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Demonstrating the Ecosystem Effects of Armored Suckermouth Catfishes (Loricariidae): A Feasibility Study Using Mesocosms

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PURPOSE: The purpose of this experiment was to design and evaluate an effective way to observe the environmental effects of Loricariidae*,* more commonly known as armored suckermouth catfishes, or simply suckermouth catfishes. The authors' solution is to use mesocosms, medium-sized containers that replicate aquatic habitat. Another aspect of the experiment focuses on exploring which environmental receptors are directly affected by the presence of the suckermouth catfishes. The targeted receptors include water quality, periphyton, phytoplankton, macrophytes, and a native fish.

Utility of Mesocosm Studies. Suckermouth catfishes, notably armadillo del rio (*Hypostomus* spp.) and sailfin catfishes (*Pterygoplichthys* spp.), have been imported as aquarium fishes since the 1890s. They have been established in North American waters since the 1960s, and reached nuisance population densities in the 1990s (Hoover et al. in preparation). The literature on invasive fishes written prior to 1990 noted no significant environmental effects from introduced populations of suckermouth catfishes, with some recent field studies even suggesting that the group represents an ecological niche unoccupied by sympatric native species (Gestring et al. 2010; Pound et al. 2011). Other studies, however, have identified impacts on imperiled fishes (Cook-Hildreth 2008), commercial fisheries (Mendoza-Alfaro et al. 2009), birds (Bunkeley-Williams et al. 1994), and aquatic mammals (Nico 2010; Nico et al., 2009). Disparity in opinion is, in part, due to the difficulty of demonstrating cause-and-effect from either highly controlled laboratory studies, which cannot duplicate complexities of real-world habitat, or from highly variable natural conditions, in which multiple factors influence response variables.

Although sometimes difficult to prove in both the laboratory and the field, environmental effects are comparatively easy to evaluate in containers that mimic natural habitat. Mesocosms are medium-sized models of aquatic ecosystems that offer several advantages over field and laboratory studies. They can be:

- replicated – to describe natural variation in physical and biological variables;
- controlled – to eliminate stochastic events (e.g., floods, droughts, immigration);
- manipulated – to create specific treatments (e.g., fish occurrence, densities); and
- monitored – to enable frequent and synoptic data collection.

There are disadvantages to the use of mesocosms. Confined spaces with limited habitat volume can instigate and intensify interactions within and among species. Homogeneous systems with minimal exposure to environmental inputs (e.g., insect drift, leaf litter, terrestrial invertebrates) can be food limited. Lack of unidirectional flow can degrade water quality and result in accumulation of waste (i.e., from feces and plant detritus). These problems, however, can be minimized or eliminated with appropriate experimental design and container management.

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The authors conducted a short-term study to evaluate feasibility of using mesocosms to identify ecosystem-level effects of suckermouth catfishes. To minimize intra- and interspecific interactions, the following were used: 1) low stocking densities of fish having different diets and microhabitat affinities but comparable size and mass; 2) floating plants and submerged structure as cover and refugia. To avoid food limitations, all tanks were fed in a manner proportionate to the number of fish stocked and their respective biomass. To maintain water quality and minimize waste accumulation, high-flow biological filters were used. These conditions were environmentally "conservative" so that any observed effects could be interpreted as realistic outcomes of the experimental treatments.

Fishes. Fish taxa used in the study were (i) armadillo del rio (*Hypostomus* spp.) and sailfin catfish (*Pterygoplichthys* spp.), both South American genera established in parts of Texas and Florida (Figure 1); (ii) golden topminnow (*Fundulus chrysotus*), a native topminnow found along the Gulf coastal plain (Figure 2). Ranges of all three taxa overlap in south Florida. Suckermouth catfishes are benthic herbivores, feeding principally on attached algae and detritus (Pound et al. 2011; Gestring et al. 2010). Golden topminnows are neustonic invertivores, feeding on a wide variety of zooplankton and aquatic insects (Hunt 1953; Hoover, unpublished data). All species were obtained from commercial dealers to ensure comparability in size within and among species.

Mesocosm Design. The mesocosms used are simple, easily constructed (and deconstructed), and low maintenance. They are cylindrical tanks, equipped with filters made from readily available materials (e.g., from a local hardware supply). Traditional filter media (floss, foam, carbon) are not used and consequently do not have to be changed. Costs of construction are comparatively low.

Mesocosms consist of commercially manufactured plastic aquaculture containers with a custom-made filter system. Tanks are blue, 122 cm in diameter, 102 cm high, with a total capacity of 1426 L. The container rests on a 1.3 cm thick pad of insulating foam and is fitted with a standard ball valve at the bottom to allow for drainage during water changes or deconstruction. The filter system is similar to an under-gravel filter, which is commonly found in the aquarium trade (Figure 3). Two Plexiglas cross-pieces about 15 cm high and 102 cm long are centered on the bottom of the tank. A polypropylene sleeve encircles these, approximately 10-13 cm from the wall of the tank. To facilitate circulation of water, holes were drilled in both of these structures. The cross-piece and sleeve support a disc of 0.5 cm thick polypropylene mesh that was made to fit snugly in the tank. Pore size of mesh is approximately 0.5 cm. The authors then secured two 5 cm diameter PVC pipes directly onto the surface of the mesh. The pipes extend above the surface of the water and terminate in a 90^{o} elbow. These serve as lift tubes to aerate and move water.

A layer of washed pea-sized gravel 8 cm thick overlies the mesh disc of the filter and water is filled to a depth of approximately 66 cm. This results in a functional habitat volume of 750 L: 475 L of living space, 185 L interspersed with gravel, and 90 L of hyporheic space below the gravel filter (Figure 4). Air from a compressor pump is bubbled up through the pipes using a chain saw fuel filter as a diffuser (Note – Chain saw fuel filters are used because they are readily available, easily cleaned with a toothbrush, and provide longer service in this type of set-up than commercially produced "air stones" used in the aquarium hobby). Bubbles diffusing through the fuel filter moved aerated water up and out the lifter tube, through the tank, and down through the gravel, providing an aerobic environment in and under the gravel. Water circulates gently in a counterclockwise direction and is pulled down through the gravel before effervescing back up through the lift tubes, mechanically filtering out particulates.

Figure 1. Suckermouth catfishes used in the mesocosm study: armadillo del rio (*Hypostomus* sp.)(upper) and sailfin catfish (*Pterygoplichthys* sp.)(lower).

Total cost of materials for each mesocosm is less than $800: tank, $295; 1.2 x 2.4 m polypropylene sheet (for disc), $151.93; PVC pipe and elbows, $30; chain saw fuel filters, $6.00 ea; ball valves, $8; Plexiglas, approx. $200.

Immediately after filling the mesocosms with de-ionized water, tanks are inoculated with approximately 1 L of "seasoned" water from established aquaria to promote adequate growth of bacterial flora for biological breakdown of waste (i.e., detoxification of nitrogenous wastes, decomposition of solid wastes). Air flow is adjusted to provide slow, steady water movement. Throughout the experiment, water is added on an "as needed" basis (usually weekly) to maintain near-constant depth and air flow is adjusted to be comparable among tanks. Diffusers require cleaning approximately every two weeks. Measured flow rates range from 9-15 L/min indicating that tanks turn over more than 17 times/day.

Figure 2. Native fish used in the mesocosm study: golden topminnow (*Fundulus chrysotus*). Photo by Mark Binkley, jonahsaquarium.com.

Cover in each mesocosm is provided by a single cinder-block on a gravel surface and aquatic plants on the water's surface. The cinderblock is 9.5 x `19.0 x 39.4 cm, with three openings that are 4 x 9 cm. Plants used are water lettuce (*Pistia stratiotes*). Together, they provide hiding places and grazing substrates at the bottom and surface of the tank. In addition, the plants provide a measurable biotic response variable since they will reflect variation in available nutrients by growth and reproduction.

Experimental Design. Mesocosms were set up in a greenhouse to provide them with natural light cycles. The greenhouse roof was covered with an 80% shade cloth to prevent overheating.

The authors used eight tanks to evaluate the effects of two controls and two treatments (two replicates each). These were:

- high density native control: 10 golden topminnow (23 g);
- low density mix: 5 golden topminnow (10 g), 4 suckermouth (15 g);
- high density mix: 10 golden topminnow (21 g) and 8 suckermouths (28 g); and
- high density exotic control: 8 suckermouth (31 g).

Mesocosms were set up 15 May 2011. Sequential stockings occurred of golden topminnows, plants, and suckermouth catfishes on 31 May, 02 Jun, and 07 Jun, respectively. Water lettuce was added to each tank so that initial surface coverage approximated 25%. Plants were decontaminated in a solution of potassium permanganate (to eliminate any attached organisms) and weighed prior to set-up. Fish were measured (nearest mm total length, TL) and weighed (nearest 0.01 g) immediately prior to stocking. The authors stocked a 2:3 ratio of male to female golden topminnow. With one exception, each tank stocked with suckermouth catfishes contained 2 sailfin catfish and the remainder were armadillo del rio.

Figure 3. Mesocosm construction (clockwise from upper left): polypropylene disc with staggered holes 5 mm in diameter and two fittings for PVC pipe; base of undergravel filter formed by disc placed on plastic rim surrounding Plexiglas cross-piece (pink pad is used as insulation under the tank); bird's eye view of undergravel filter with lift tubes in place; bird's eye view of assembled mesocosm with gravel, cinder block, and plants in place and water circulating.

Mesocosms were maintained and monitored for eight weeks. Mesocosms were checked (for mortalities or spawning) and fish were fed commercial flake food daily (3% of total fish biomass). Monitoring took place bi-weekly (or more frequently). Monitoring consisted of measurements of water quality (temperature, conductivity, pH, dissolved oxygen, and turbidity) and photographs of the tank walls (periphyton) and of the water's surface (water lettuce). During the course of the experiment, if a fish was found dead, it was replaced with a fish of similar size. At the conclusion of the experiment, the fish were counted, measured, and weighed and total plants weighed. The tanks were deconstructed 09 Aug 2011.

The Effects of Suckermouth Catfishes in Mesocosms. Parameters measured at the end of the experiment showed no indication that suckermouth catfishes produced noticeable effects in water quality (Table 1). All mesocosms were warm (28 C), moderate in conductivity (182-218 uS/cm), normoxic (7.51-8.26 ppm), and with near-neutral pH (7.39-7.64 pH). The coefficient of variation among all mesocosms < 7%.

Suckermouth catfishes eliminated periphyton from all mesocosms in which they were stocked (Figure 5). Dark blue-green periphyton was conspicuous in both native controls. No periphyton was observed in the other containers. This indicated that there were no interactive effects among the fishes and no density effects of suckermouth catfishes.

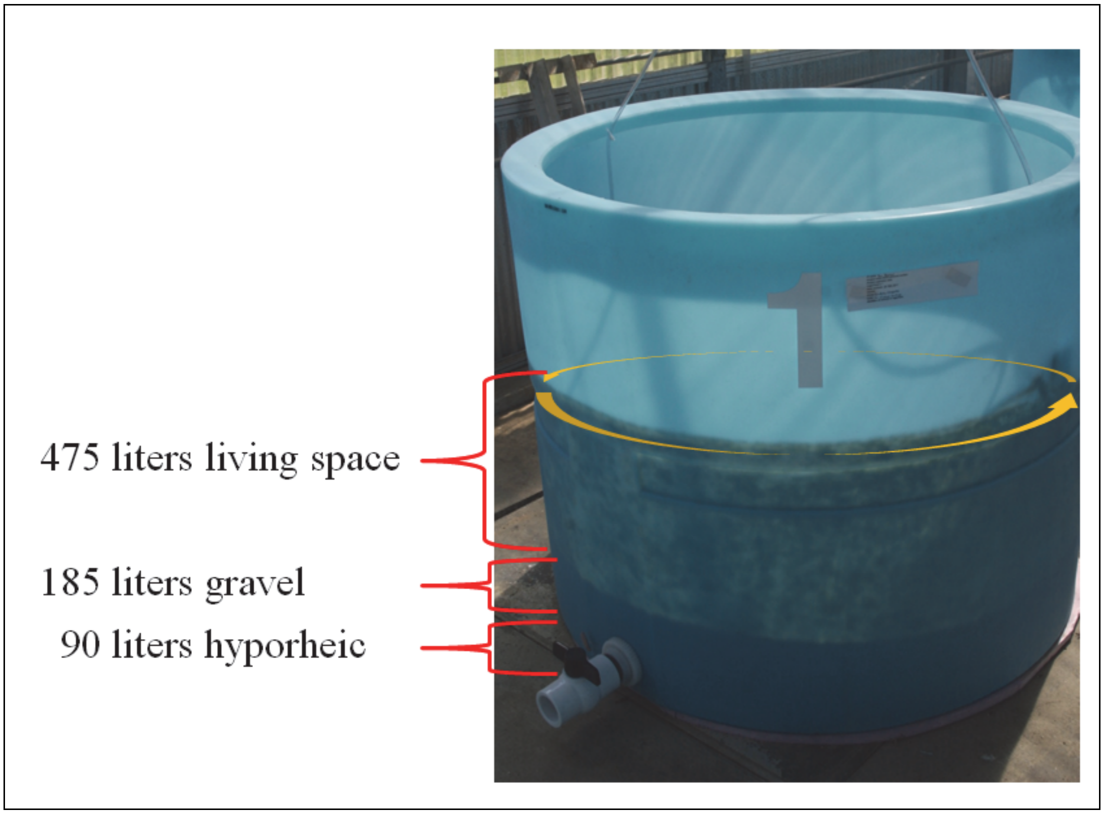

Figure 4. Lateral view of established mesocosm. Ball-valve at base allows water to be drained from bottom of tank through gravel preventing loss of fish during deconstruction. Airlines supplying lift tubes are seen entering at top of tank.

Table 1. Mesocosm water quality, after eight weeks, with assemblages of native golden topminnows only, low and high densities of native golden topminnows with exotic suckermouth catfishes, and exotic suckermouth catfishes only. Coefficients of variations are presented for the eight values.

	Native Control		Low Density Mix		High Density Mix		Exotic Control		CV N=8
Replicate	1	2	1	2	1	2	1	2	---
Temperature (C)	28.0	28.0	28.1	28.4	28.2	28.2	28.2	28.1	0.5%
Conductivity (µS/cm)	182	203	218	194	213	209	194	217	6.3%
Dissolved oxygen (ppm)	7.70	7.77	7.40	7.64	8.26	7.61	7.74	7.51	3.3%
pH	7.39	7.51	7.52	7.56	7.64	7.63	7.52	7.53	1.0%

Conspicuous growths of phytoplankton elevated turbidity in the mixed species tanks, with effects most pronounced in high density mesocosms (Figure 6). Turbidity decreased ~ 0.5 NTUs in native control, increased < 2 NTUs in exotic control, ~ 2 NTUs in low density mix, and > 6 NTUs in the high density mix. Turbidity data indicated that phytoplankton growth was associated with the number of suckermouth catfishes but that the effect was enhanced by the presence of golden topminnows.

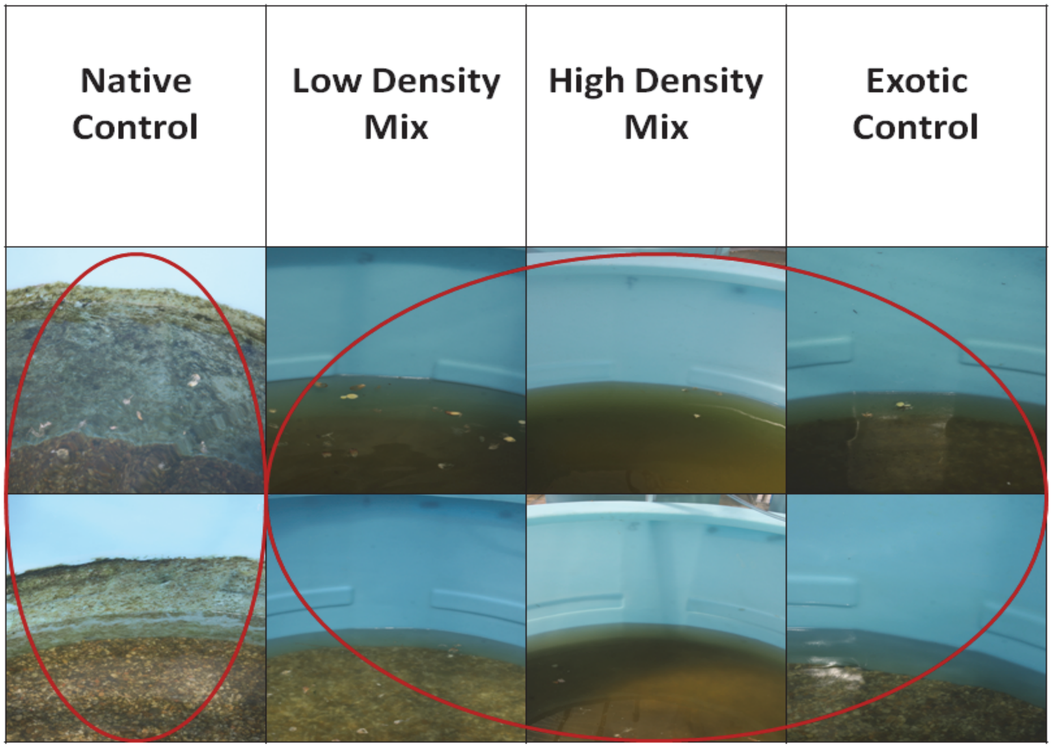

Figure 5. Periphyton growth on meoscosm walls after eight weeks. Mesocosms have been drained and are < 30% full. Two replicates with golden topminnows had conspicuous algal growths. Mixed assemblages of golden topminnows and suckermouth catfishes (low and high density) and suckermouth catfishes showed no visible algal growth.

Macrophyte growth was inhibited in the presence of mixed fish species (Figure 7). Macrophyte biomass increased > 0.50 kg/8 weeks in all containers, but values were lower and more consistent, 0.55-0.65 kg/8 weeks, in mixed species mesocosms, than in native and exotic controls, 0.65-0.95 kg/8 weeks. Growth data reflected a progressive change in available nutrients over time (from daily food input, accumulation of nitrates, etc.) but indicated an interactive effect of the two fish species.

There were no consistent impacts of suckermouth catfishes on golden topminnow (Table 2). Mortality was low ($\leq$20%). Young-of-year were observed in a single replicate of native control, low density mix, and high density mix. Likewise, apparent change in biomass increased 9.9-33.0% in a single replicate, and decreased 1.1-15.0% in the other replicate for each group of replicates.

Conceptual Model. The authors believe that differences among mesocosms in phytoplankton density (measured as turbidity) and macrophyte growth (measured as change in biomass) resulted from impacts of suckermouth catfishes on a simple food web (Figure 8). In the absence of suckermouth catfishes, periphyton grows thickly, providing cover for filter-feeding aquatic invertebrates that graze on phytoplankton maintaining water clarity. Suckermouth catfishes, however, eliminate periphyton, and cover for invertebrates, making the invertebrates more vulnerable to predation by other fishes. Suckermouth catfishes also produce substantial quantities of feces which make nutrients more available to algae in the water column. At low fish densities, invertebrates are lightly suppressed (from predation), phytoplankton increases slightly (from reduced herbivory and increased nutrients), increasing turbidity.

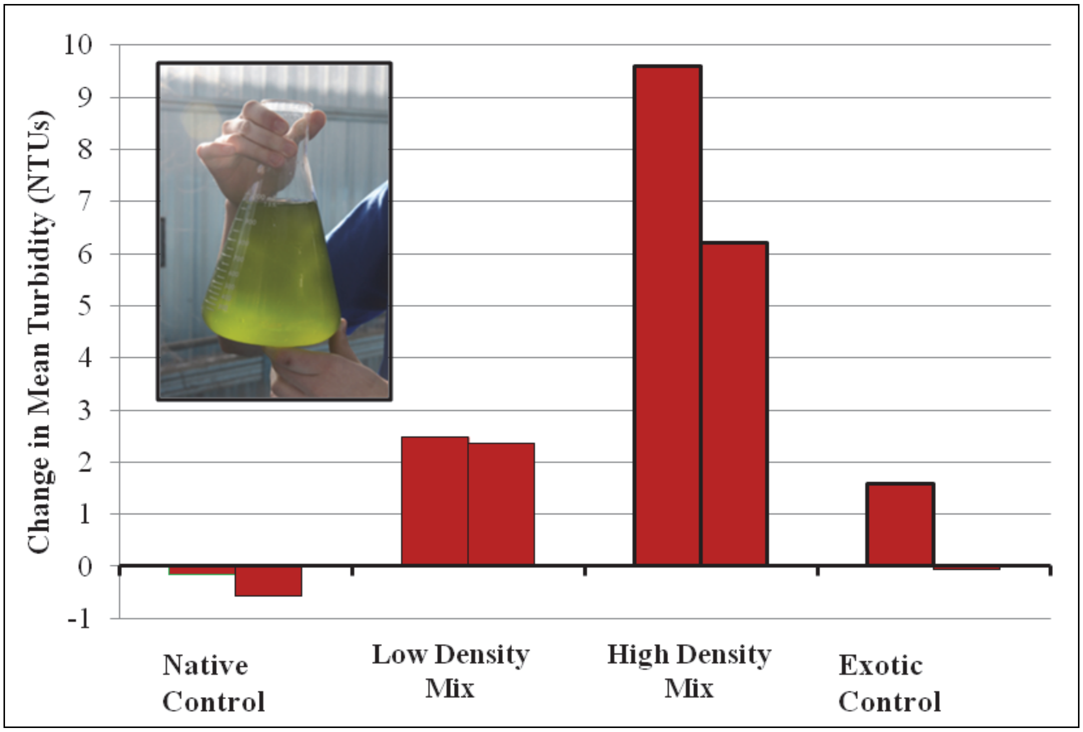

Figure 6. Net change in mesocosm turbidity after eight weeks. Turbidity is an indirect measure of phytoplankton density since suspended fine sediments in mesocosm are negligible and algal growth was obvious in water samples (inset).

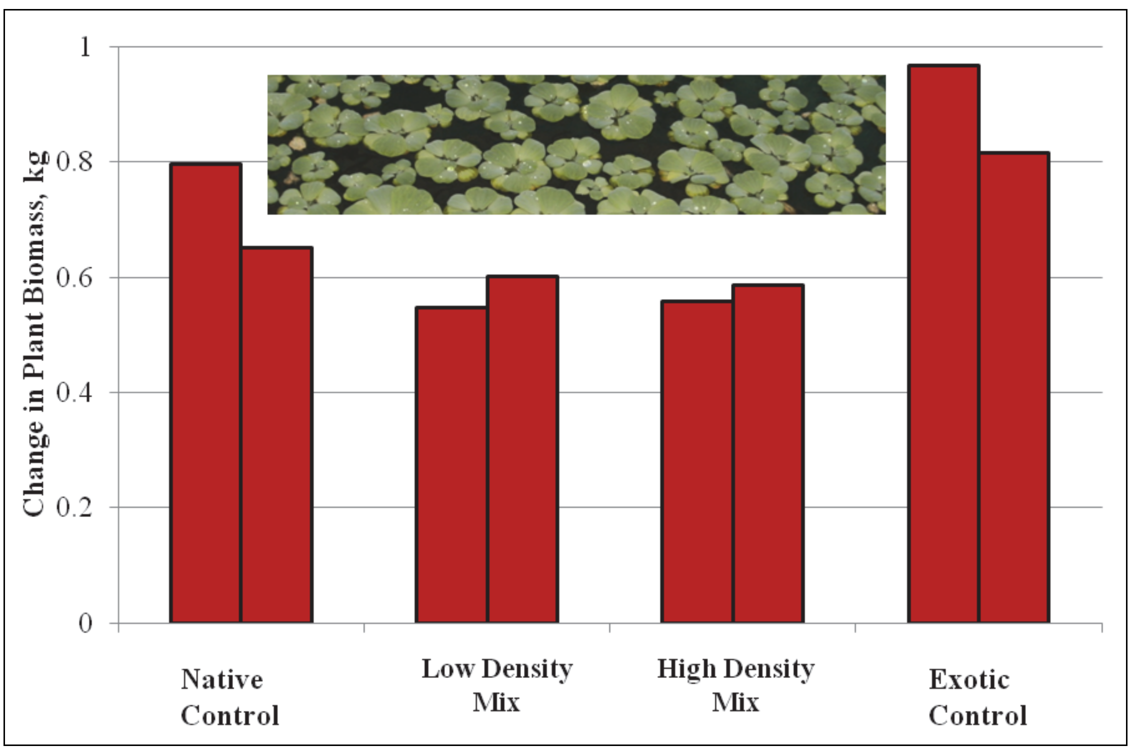

Figure 7. Net change in mesocosm biomass of macrophytes after eight weeks. A single species, water lettuce (*Pistia stratiotes*), was used (inset).

Table 2. Effects of suckermouth catfishes on golden topminnow.

	Native Control		Low Density Mix		High Density Mix	
Replicate	1	2	1	2	1	2
Mortality (%)	10	10	20	0	20	20
Spawning	0	+	+	0	0	+
Change in Biomass (%)	9.9	-1.1	-15.0	33.0	-9.4	31.1

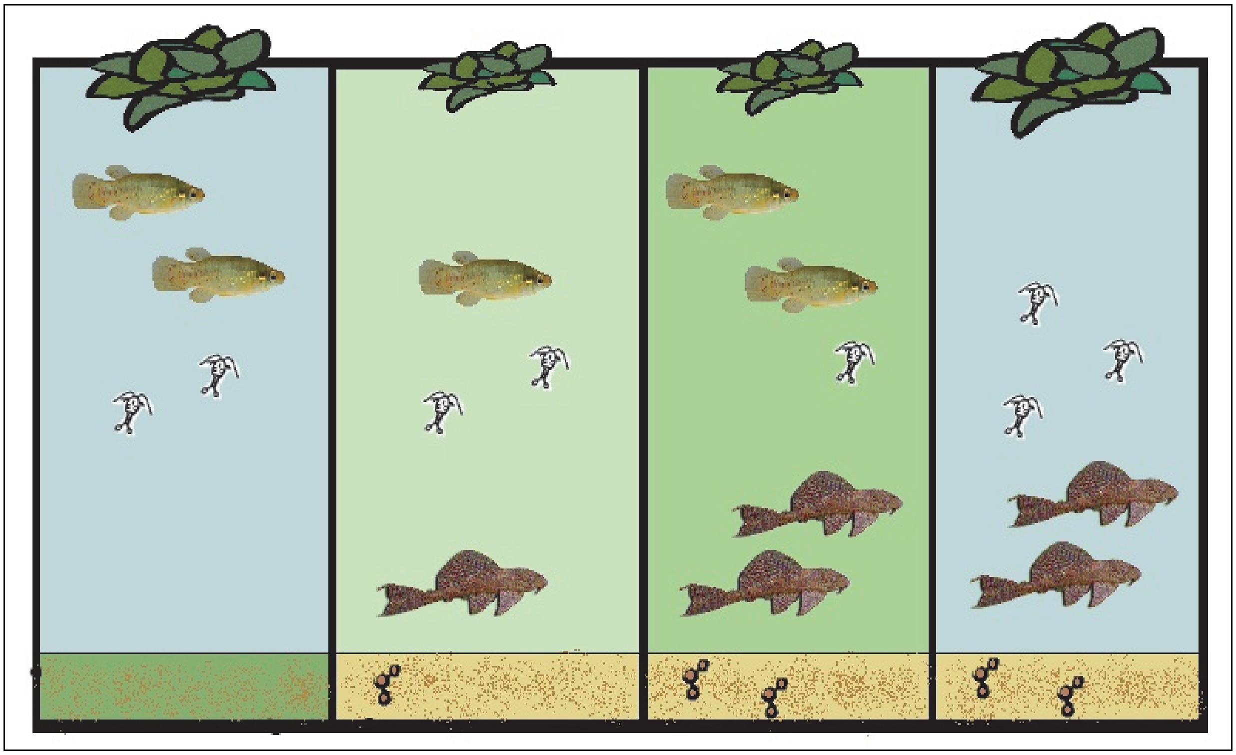

Figure 8. Conceptual model of ecosystem effects of suckermouth catfishes based on an 8-week mesocosm study. Symbols (top to bottom) represent water lettuce, golden topminnows, zooplankton, suckermouth catfishes, periphyton, and suckermouth catfish feces. Fill colors represent varying levels of phytoplankton growth: blue, low; light green, moderate; dark green, high. All elements in model, with the exception of zooplankton, are based on empirical data and personal observation.

At high fish densities, the same effects are exacerbated, with invertebrates severely suppressed from intense predation, phytoplankton increasing substantially (from elimination of herbivory and greatly increased nutrients), elevating turbidity even more. Greater densities of phytoplankton usurp nutrients from macrophytes reducing their growth. When suckermouth catfishes are the only species of fish, aquatic invertebrates survive (due to the absence of predation) and can graze phytoplankton and maintain water clarity, albeit incompletely due to fecal production by catfish.

The above explanation is consistent with all data collected and all observations made during the course of this experiment. The authors did not obtain data on aquatic invertebrates, however, and light-traps set in mesocosms the night before deconstruction failed to collect large zooplankton. It is not unreasonable to assume invertebrate colonization of mesocosms. They were inoculated with aged aquarium water in which occurrence of zooplankton (e.g., protozoans, rotifers, copepods) is highly probable. The greenhouse was periodically opened to the outdoors, so drifting and flying insects had access to tanks. Terrestrial arthropods (e.g., spiders) and aquatic insects (e.g., larval Chironomidae) were frequently observed above the surface film and in the water, respectively.

Future Studies. The authors' results are compatible with the current dichotomy in thought regarding the environmental effects of suckermouth catfishes. Impacts on a native fish were not apparent, apparently due to extreme ecological differences and lack of direct interactions between the species. Effects on other organisms were apparent and substantial, however. An experiment of greater duration, resulting in more extreme effects on plant standing crops, may have eventually impacted the native fish population.

This study demonstrated that mesocosms of modest size and cost could be used to identify ecosystem level impacts of suckermouth catfishes, which — in turn — might be applied to future field assessments of suckermouth catfish ecology. The authors recommend that future mesocosm studies evaluate herbivory and plant standing crops in greater detail: i) interactions of suckermouth catfishes with native periphyton grazers (e.g., snails, stoneroller minnows); ii) effects on nuisance species of aquatic vegetation (e.g., water hyacinth, giant salvinia); iii) effects on direct measures of phytoplankton standing crop (e.g., algal cell densities, concentration of chlorophyll). The authors also recommend that field studies of suckermouth catfishes assess potential impacts more synoptically by quantifying physical habitat, primary producers, and primary consumers.

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